

# SiO chimneys and supershells in M82 <sup>1</sup>

S.García-Burillo  
J.Martín-Pintado

A.Fuente

*Observatorio Astronómico Nacional (OAN), Campus Universitario  
Apdo.1143, Alcalá de Henares, E-28800, Madrid, SPAIN  
burillo@oan.es, martin@oan.es, fuente@oan.es*

and

R. Neri

*Institut de Radio Astronomie Millimétrique (IRAM)  
300, Rue de la Piscine, 38406-St.Mt.d'Hères, FRANCE  
neri@iram.fr*

## ABSTRACT

In this letter we present the first images of the emission of SiO and H<sup>13</sup>CO<sup>+</sup> in the nucleus of the starburst galaxy M82. Contrary to other molecular species, which mainly trace the distribution of the star forming molecular gas within the disk, the SiO emission extends noticeably out of the galaxy plane. The bulk of the SiO emission is restricted to two major features. The first feature, referred to as the SiO supershell, is an open shell of 150 pc diameter, located 120 pc west from the galaxy center. The SiO supershell represents the inner front of a molecular shell expanding at  $\sim 40 \text{ km s}^{-1}$ , produced by mass ejection around a supercluster of young stars containing SNR 41.95+57.5. The second feature is a vertical filament, referred to as the SiO chimney, emanating from the disk at 200 pc east from the galaxy center. The SiO chimney reaches a 500 pc vertical height and it is associated with the most prominent chimney identified in radiocontinuum maps. The kinematics, morphology, and fractional abundances of the SiO gas features in M82 can be explained in the framework of shocked chemistry driven by local episodes of gas ejection from the starburst disk. The SiO emission stands out as a privileged tracer of the disk-halo interface in M82. We speculate that the chimney and the supershell, each injecting  $\sim 10^7 M_{\odot}$  of molecular gas, are two different evolutionary stages in the outflow phenomenon building up the gaseous halo.

*Subject headings:* galaxies: individual(M82)<sup>1</sup>–galaxies: starburst–galaxies: nuclei–ISM: bubbles–ISM: molecules–radio lines: galaxies

## 1. Introduction

The detection of large-scale outflows in over a dozen starburst galaxies has confirmed the overall predictions of the galactic wind model, first proposed by Chevalier & Clegg (1985). It is widely accepted that the driving mechanism of the outflow phenomenon in starbursts is linked to the creation of expanding shells of hot gas by supernovae. At the end of the starburst cycle, the resulting high supernova rate creates a rarefied wind of hot gas in the disk (with temperatures of  $\sim 10^7\text{K}$ ) at several thousands of  $\text{kms}^{-1}$ . Different *hot bubbles* could merge and blow out into the halo, entraining surrounding cold gas and dust at several hundreds of  $\text{kms}^{-1}$ . These bubbles, although initially spherical, may evolve eventually into vertical chimneys of gas (Norman & Ikeuchi 1989; Koo & McKee 1992; Alton, Davies, & Bianchi 1999). The halo outflow would be built up in the end by the local injection of gas from the disk. The details of this secular process, which should drive large-scale shocks in the molecular gas, remain unknown however, partly because we lack of observational constraints.

M82 is the closest galaxy experiencing a massive star forming episode (Rieke et al. 1980; Wills et al. 1999). Its nuclear starburst, located in the central 1 Kpc, has been studied in virtually all wavebands from X-rays to the radio domain. X-rays and optical observations have shown the existence of a large-scale biconical out-

flow of hot gas coming out of the plane from the nucleus of M82 (Bregman, Schulman, & Tomisaka 1995; Shopbell & Bland-Hawthorn 1998). This massive outflow is also observed at large scales in the cold gas and dust (Seaquist & Clark 2001; Alton et al. 1999). At smaller scales, close to the disk-halo interface of M82, there is observational evidence of local sources of gas injection. Using 1.4 and 5 GHz VLA data, Wills et al. (1999) have shown the existence of a large (diameter  $\sim 120$  pc) expanding shell of ionized gas, close to the supernova remnant SNR 41.95+57.5. A molecular gas counterpart of this supershell was tentatively identified by Neininger et al. (1998) and later discussed in Weiss et al. (1999, 2001) and Matsushita et al. (2000). Wills et al. (1999) detected also the signature of four chimneys of hot gas. The most prominent one, located on the northeastern side, reaches a vertical height of  $\sim 200$  pc. The molecular gas counterpart of the chimney has remained so far undetected (see Weiss et al. (2001)).

In this letter we present the first high-resolution ( $\sim 5''$ ) image of the emission of silicon monoxide (SiO) in the nucleus of M82. SiO is known to be a privileged tracer of large-scale shocks in the interstellar medium of galaxies (Martín-Pintado et al. 1997; García-Burillo et al. 2000; García-Burillo & Martín-Pintado 2001). The SiO emission is used in this work to study the occurrence of shocks in the halo-disk interface of M82. We present the first evidence of a SiO expanding supershell, related with the superbubble of hot gas, and the first detection of a molecular gas chimney associated with a violent mass ejection event in

---

<sup>1</sup>Based on observations carried out with the IRAM Plateau de Bure Interferometer. IRAM is supported by INSU/CNRS (France), MPG (Germany) and IGN (Spain).

M82.

## 2. Observations

Observations of M82 were completed with the IRAM array at Plateau de Bure (France) during 1999 June. We observed simultaneously the J=2–1 line of SiO (86.847 GHz), and the J=1–0 line of H<sup>13</sup>CO<sup>+</sup> (86.754 GHz), using the CD set of configurations. The 55'' primary beam field of the array was phase-centered at  $\alpha_{J2000}=09^h55^m51.9^s$  and  $\delta_{J2000}=69^\circ40'47.1''$ , which corresponds to the 2.2 $\mu$ m peak (Joy, Lester, & Harvey 1987). We adjusted the spectral correlator to give a contiguous bandwidth of 1500 km s<sup>-1</sup>. The frequency resolution was set to 2.5 MHz (8.64 km s<sup>-1</sup>). We calibrated visibilities using as amplitude and phase references 0836+710 and 0716+714. The absolute flux scale and receiver passband shape were derived on MWC 349 and 3C 273, respectively. Cleaned maps are 256 × 256 pixels in extent, with a pixel size of 0.6''. The synthesized beam is almost circular (5.9'' × 5.6'', PA=105°). The rms noise level in 2.5 MHz wide channel maps, derived after subtraction of the continuum emission, is 1 mJy/beam (5 mK). We take as distance to M82, D=3.9 Mpc (Sakai & Madore 1999); the latter implies 1''~20 pc.

## 3. Results

Fig.1 shows the velocity-integrated intensity map of SiO(2-1) in the central 1 Kpc of M82. Two specific regions in the nucleus of M82 contain the bulk of the SiO emission, which extends noticeably out of the galaxy plane. On the eastern side of the disk, a vertical feature emanates from

the disk at  $(\Delta\alpha, \Delta\delta) \sim (+10'', +5'')$ , indicating the blow-out of molecular gas out of the plane of M82. This feature extends out to the edge of the primary beam on both sides of the plane along PA~−40°, reaching a vertical height of ~500 pc northwards. It is however unresolved transversely. The second dominant feature in the map, centered at (−5'', −2''), is an arc-like structure closed on its southern hemisphere. Two emission peaks, ~150 pc apart, define the arc diameter measured along the major axis. We describe below these two prominent sources of the SiO map, hereafter referred to as the *chimney* and the *super-shell*, and discuss their relation with the local mass ejection signatures observed in the disk of M82.

### 3.1. The SiO chimney

The SiO chimney is closely related to a radiocontinuum (RC) chimney identified by Wills et al. (1999), which represents a signature of ejection of ionized gas. The RC chimney in Fig.1 is delimited by two black-shaded emission blobs on the northern edge of the continuum map. The filament stands out due to free-free absorption by the ionized gas lying inside. Although the RC chimney is not the only ejection feature of ionized gas in M82, it is the most significant blow-out signature. Our detection of SiO along this chimney shows that molecular gas can be entrained and survive up to high vertical z-distances (~500 pc). The <sup>12</sup>CO(2–1) interferometer map of Weiss et al. (2001) does not show a clear signature linked to the SiO chimney. Although there is an emission peak in the eastern end of the map, near the southern end of the SiO chim-

ney, Weiss et al. (2001) have discarded it as an artifact. At much larger scales however ( $\sim \pm 2\text{--}3\text{ Kpc}$ ), the low-resolution  $^{12}\text{CO}$  maps of the galaxy's halo (Thuma et al. 2000; Seaquist & Clark 2001) show evidence that a giant molecular outflow exists in M82. Contrary to the high-density gas ( $n(\text{H}_2) > 10^{4\text{--}5}\text{ cm}^{-3}$ ) probed locally by the SiO emission along the chimney, the halo gas traced by  $^{12}\text{CO}$  at larger scales is mostly diffuse ( $n(\text{H}_2) \sim 10^3\text{ cm}^{-3}$ , see Seaquist & Clark (2001)). This is expected if the SiO emission arises from a thin layer of shocked gas (see below).

The SiO radial velocities measured along the chimney indicate that the gas flow is driven by an ejection event, rather than by the rotation of the galaxy. Fig.2 shows the channel maps for three velocity intervals containing the bulk of the SiO emission. The chimney feature stands out in the  $100\text{--}240\text{ km s}^{-1}$  range. The strongest SiO emission on the northern and southern segments of the chimney appears at  $v \sim 150\text{ km s}^{-1}$ , i.e. at *forbidden* velocities,  $\sim 100\text{ km s}^{-1}$  blueshifted relative to the systemic velocity ( $v_{\text{sys}} \sim 225 \pm 20\text{ km s}^{-1}$ ). The emission from a filament of ionized gas lying near the SiO chimney has been studied by Shopbell & Bland-Hawthorn (1998), using  $\text{H}\alpha + \text{NII}$  lines. Most interestingly, the bluest component detected in the optical lines appears also at  $v \sim 150\text{ km s}^{-1}$ . The coincidence in radial velocities found between SiO and  $\text{H}\alpha + \text{NII}$  suggests that the working surfaces for molecular and ionized gas share a similar geometry.

The SiO chimney is also detected in  $\text{H}^{13}\text{CO}^+$  at similar velocities, although at a significantly lower level (see Fig.2). The  $\text{H}^{13}\text{CO}^+$  emission is strongest in the south-

ern segment of the chimney, at both *forbidden* and *permitted* velocities.  $\text{H}^{13}\text{CO}^+$  is best detected at the base of the chimney, close to the galaxy disk. We will adopt the same approach to the one used by García-Burillo et al. (2000) in NGC 253 to estimate the molecular mass of dense gas ( $M(\text{H}_2)$ ) and the SiO fractional abundances ( $X(\text{SiO})$ ) in the chimney. Assuming that the physical parameters of the SiO gas are similar in M82 and in NGC 253 ( $n(\text{H}_2) = 1\text{--}10 \times 10^5\text{ cm}^{-3}$  and  $T_k = 50\text{ K}$ ), we derive the SiO/ $\text{H}^{13}\text{CO}^+$  abundance ratio that fits the observed SiO/ $\text{H}^{13}\text{CO}^+$  line ratio, using a Large Velocity Gradient (LVG) model. If we adopt a canonical value for  $X(\text{H}^{13}\text{CO}^+) = 10^{-10}$ , the implied SiO abundance would range from  $\sim 2 \times 10^{-10}$  to  $> 3.5 \times 10^{-10}$ . The SiO abundance is significantly enhanced in the chimney, surpassing by  $\sim 1\text{--}2$  orders of magnitude the typical value of quiescent gas environments (Ziurys, Friberg, & Irvine 1989). This local value of the SiO abundance is also remarkably larger than the global estimate of  $X(\text{SiO})$  for the whole M82 disk ( $\sim 10^{-11}$ ), first derived by Sage & Ziurys (1995). Conclusions on the enhancement of the SiO abundance in the chimney are strengthened if we assume a lower density for the gas: for  $n(\text{H}_2) = 5 \times 10^4\text{ cm}^{-3}$ , we derive  $X(\text{SiO}) \sim 10^{-9}$  (see detailed discussion in García-Burillo et al. (2000)). The present estimates indicate that shock chemistry is heavily processing molecular gas upon ejection. We can derive the  $M(\text{H}_2)$  mass contained in the chimney by integrating the LVG-based estimate of  $N(\text{H}_2)$ . We obtain  $M(\text{H}_2) \sim 6 \times 10^6 M_\odot$ .

### 3.2. The SiO supershell

The SiO supershell is associated with similar signatures of gas ejection located around SNR 41.95+57.5. Wills et al. (1999) have reported the existence of an expanding shell of ionized gas of  $\sim 120$  pc diameter, near SNR 41.95+57.5, which is also identified in the NeII map of Achtermann & Lacy (1995). Weiss et al. (1999, 2001) and Matsushita et al. (2000) found in their  $^{12}\text{CO}$  interferometer maps further evidence of an expanding supershell of molecular gas around SNR 41.95+57.5. The maps of the ionized and molecular supershells show morphological differences, however. The emission of ionized gas seems to lie inside the CO supershell. Like the ionized gas, the SiO supershell (of  $\sim 150$  pc diameter) seems also smaller than its CO counterpart (of  $\sim 200$  pc diameter). The southern wall of the SiO supershell represents the inner front of the CO shell which is also seen to protrude southwards in the map of Weiss et al. (2001). On larger scales, Wills et al. (1999) have identified a spur-like filament extending into the north from the supershell center in the disk. The morphology of the SiO supershell, closed southwards, confirms that the ejection has broken the primary molecular shell to the north.

The kinematics of SiO in the supershell are roughly consistent with the expansion scenario depicted by Weiss et al. (1999, 2001). The SiO emission at the center of the supershell (at  $\sim (-5'', -2'')$ ) show hints of a double-peaked profile. The strongest (weakest) component at  $v \sim 100 \text{ km s}^{-1}$  ( $v \sim 180 \text{ km s}^{-1}$ ) would represent the approaching (receding) side of a molecular shell in the galactic disk, ex-

panding at  $v_{exp} \sim 40 \text{ km s}^{-1}$ . As expected for an expanding shell, the SiO spectrum at its southern end (at  $\sim (-2'', -8'')$ ) has one component centered at  $v \sim 140 \text{ km s}^{-1}$ .

Under the same assumptions of section 3.1 we can estimate both the mass of dense molecular gas  $M(\text{H}_2)$  and the fractional abundance of SiO in the supershell. The inferred SiO abundances are  $X(\text{SiO}) \sim 0.4 - 1 \cdot 10^{-10}$ , namely a factor of  $\sim 4$  lower than in the SiO chimney. Processing of molecular gas by shocks seems milder in the supershell, especially within the galaxy disk where the abundance of SiO approaches values typically found in Photon-Dominated Regions (PDR) ( $X(\text{SiO}) \sim 10^{-11}$ ; see Walmsley, Pineau des Forêts, & Flower (1999)). The derived mass of molecular gas in the SiO supershell is  $M(\text{H}_2) \sim 1.6 \cdot 10^7 M_\odot$ , roughly in agreement with the value derived by Weiss et al. (1999), using  $^{12}\text{CO}(2-1)$  data.

### 4. Discussion and Conclusions

Numerical simulations studying the evolution of outflows in starbursts (Tomisaka & Bregman 1993; Suchkov et al. 1996) have predicted that the resulting hot galactic wind, observed in X-rays and diffuse H $\alpha$  emission, may drag the cooler and denser material of the blown-out disk up to 1–2 kpc above the plane of a galaxy. These models show that, near the base of the outflow, at a scale height of  $\sim 500$  pc, filaments of cold disk material should be present. The detection of SiO emission from a prominent chimney and a giant shell in M 82 provides a nice confirmation of these models, proving that the entrained cold material can survive in molecular form

in spite of the high-velocities (several hundreds  $\text{kms}^{-1}$  in the SiO chimney) involved upon ejection. The chemical processing of dust grains by shocks can be at work during the blow-out of the disk; the latter naturally explains the high abundances of SiO measured in the molecular gas of the chimney, and to a lesser extent, in the supershell. Contrary to other species, which mainly trace the distribution of the star forming molecular gas within the disk, SiO stands out as a privileged tracer of the disk-halo interconnection in M 82.

Several scenarios can be envisaged to account for the different morphologies and properties characterizing the chimney and the supershell. We discuss the case where the differences might reflect the evolution expected for an ejection event from the disk. Furthermore, the energies required to form the chimney or the supershell may largely differ. Their unlike morphologies may also result from the action of collimating mechanisms shaping differently the outflow of molecular gas.

In the frame of the evolutionary scenario, the SiO chimney, extended up to 500 pc above the galaxy plane, would be an evolved ejection episode. In contrast, the supershell (of  $\sim 75$  pc radius) would be just starting to undergo a blow-out. Wills et al. (1999) have come to similar conclusions analyzing the morphologies of the related radiocontinuum features. Additional insight is gained by estimating the kinematical ages of the SiO structures. The reported size ( $\sim 75$  pc radius) and expansion velocity ( $\sim 40 \pm 5 \text{ kms}^{-1}$ ) allows to infer an age of  $\sim 2 \cdot 10^6$  years for the SiO supershell. This is probably an upper limit, as the gas flow has been likely decelerated during the

expansion, as already pointed out by Weiss et al. (1999). Deriving the kinematical age of the chimney is less straightforward, however. Although the radial velocities measured along the chimney reveal an ejection-dominated flow, the value of deprojected velocities are strongly model-dependent. A global model for the molecular gas outflow needs a complete high-resolution mapping of the molecular halo in M 82. However, we found in our data evidence that the dynamics of the entrained molecular gas is similar to the ionized gas near the location of the SiO chimney. If the model of Shopbell & Bland-Hawthorn (1998) (based on a global fit on several optical filaments) held for the SiO chimney, the estimated ejection velocity would be  $\sim 500 \text{ kms}^{-1}$ . The derived kinematical age for the SiO chimney ( $\sim 10^6$  years) would not be significantly different from the one determined for the supershell. As the evolutionary link hypothesis depicted above is probably correct, this result suggests that the time-scale for evolution is shorter in the chimney than in the supershell. This may indicate that the energy required to create the chimney is comparatively larger.

We estimate that the kinetic energy contained in the SiO supershell is  $E_{kin} \sim 2 \cdot 10^{53}$  ergs. Assuming that the typical type-II supernova energy input is  $10^{51}$  ergs, and that only  $\sim 10\%$  of the explosion energy is transferred to kinetic energy (see numerical models of Chevalier (1974)), the formation of the supershell would require  $\sim 2 \cdot 10^3$  correlated explosions in  $10^6$  years. Most notably, the derived kinetic energy of the SiO chimney is much larger:  $E_{kin} \sim 10^{55}$  ergs (taking  $\sim 500 \text{ kms}^{-1}$  as ejection velocity); this would require  $10^5$  correlated super-

novae in  $10^6$  years, namely a supernova rate of  $0.1 \text{ SN yr}^{-1}$ . This result holds even in the improbable scenario where the outflow is nearly parallel to the galaxy plane. In this case we obtain a lower limit of  $E_{kin} \sim 4 \cdot 10^{53} \text{ ergs}$  for the chimney. This is still a factor 2-3 larger than derived for the supershell. Although the energy requirements to form the SiO chimney might be very stringent if gas velocities are close to hundreds of  $\text{kms}^{-1}$ , the measured supernova rate in the central disk of M82 ( $0.1 \text{ SN yr}^{-1}$ ; see Kronberg, Biermann, & Schwab (1985)) may account for it.

We can speculate that the large-scale molecular gas halo of M82 detected by Seaquist & Clark (2001), has been built up by local episodes of gas injection from the disk. The two SiO features reported in this letter, injecting each  $\sim 10^7 M_{\odot}$  gas, provides a tantalizing evidence that this secular process is at work in M82. Seaquist & Clark (2001) estimated a molecular gas mass of the halo of  $\sim 5 \cdot 10^8 M_{\odot}$ ; the latter implies we would need 20-50 of these local episodes to build up the halo. In view of the available estimates for the age of the starburst ( $5 \cdot 10^7$ - $10^8$  years), and the energy deposited by supernovae explosions during this time ( $\sim 10^{58}$  ergs) we can conclude that both the time-scales and the energy input required to form 20-50 of these ejection episodes are well accounted for by the starburst engine in M82.

This work has been partially supported by the Spanish DGES under grant number AYA2000-927 and CICYT-PNIE under grant PNE014-2000-C. We heartily thank Karen Wills and Axel Weiss for providing free access to their data. We acknowledge

the IRAM staff from the Plateau de Bure and from Grenoble for carrying the observations and help provided during the data reduction.

## REFERENCES

- Achtermann, J. M., & Lacy, J. H. 1995, *ApJ*, 439, 163
- Alton, P. B., Davies, J. I., & Bianchi, S. 1999, *A&A*, 343, 51
- Bregman, J. N., Schulman, E., & Tomisaka, K. 1995, *ApJ*, 439, 155
- Chevalier R. A. 1974, *ApJ*, 188, 501
- Chevalier R. A., & Clegg, A. W. 1985, *Nature*, 317, 44
- García-Burillo, S., Martín-Pintado, J., Fuente, A., & Neri, R. 2000, *A&A*, 355, 499
- García-Burillo, S., & Martín-Pintado, J. 2001, *The Promise of FIRST*, ESA SP-460, ed. by Pillbratt G. et al., in press
- Joy, M., Lester, D. F., & Harvey, P. M. 1987, *ApJ*, 319, 314
- Koo, B. C., & McKee, C. F. 1992, *ApJ*, 388, 93
- Kronberg, P. P., Biermann, P., & Schwab, F. R. 1985, *ApJ*, 291, 693
- Martín-Pintado, J., de Vicente, P., Fuente, A., & Planesas, P. 1997, *ApJ*, 482, L45
- Matsushita, S., Kawabe, R., Matsumoto, H., Tsuru, T. G., Kohno, K., Morita, K., Okumura, S. K., & Vila-Vilaró, B. 2000, *ApJ*, 545, L107

- Neininger, N., Guélin, M., Klein, U.,  
García-Burillo, & Wielebinski, R. 1998,  
A&A, 339, 737
- Norman, C. A., & Ikeuchi, S. 1989, ApJ,  
345, 372
- Rieke, G. H., Lebofsky, M. J., Thompson,  
R. I., Low, F. J., & Tokunaga, A. T.  
1980, ApJ, 238, 24
- Sage, L. J., & Ziurys, L. M. 1995, ApJ,  
447, 625
- Sakai, S., & Madore, B. F. 1999, ApJ, 526,  
599
- Sequist, E. R., & Clark, J. 2001, ApJ,  
552, 133
- Shopbell, P. L., & Bland-Hawthorn, J.  
1998, ApJ, 493, 129
- Suchkov, A. A., Berman, V. G., Heckman,  
T. M., & Balsara, D. S. 1996, ApJ, 463,  
528
- Tomisaka, K., & Bregman, J. N. 1993,  
PASJ, 45, 513
- Thuma, G., Neininger, N., Klein, U., &  
Wielebinski, R. 2000, A&A, 358, 65
- Walmsley, C. M., Pineau des Forêts, G., &  
Flower, D. R. 1999, A&A, 342, 542
- Weiss, A., Walter, F., Neininger, N., &  
Klein, U. 1999, A&A, 345, L23
- Weiss, A., Neininger, N., Hüttemeister, S.,  
& Klein, U. 2001, A&A, 365, 571
- Wills, K., Redman, M. P., Muxlow, W. B.,  
& Pedlar, A. 1999, MNRAS, 309, 395
- Ziurys, L. M., Friberg, P., & Irvine, W. M.  
1989, ApJ, 343, 201

---

This 2-column preprint was prepared with the  
AAS L<sup>A</sup>T<sub>E</sub>X macros v5.0.



Fig. 1.— The velocity-integrated intensity map of SiO( $v=0, J=2-1$ ), in the central region of M 82 (levels: 0.10 to 0.35 Jy beam $^{-1}$  kms $^{-1}$  by steps of 0.05 Jy beam $^{-1}$  kms $^{-1}$ ;  $1\sigma=0.040$  Jy beam $^{-1}$  kms $^{-1}$ ), is overlaid with the radiocontinuum emission image at 4.8GHz from Wills et al. (1999) (gray-scale saturated from 1.5E-04 Jy beam $^{-1}$  to 4E-04 Jy beam $^{-1}$ ). The outer circle delimits the Bure primary beam field at 87 GHz (55"). The synthesized beam (5.9"  $\times$  5.6") is pictured on the bottom left corner. A white line traces the galaxy major axis at  $PA_{disk}=70^\circ$ . ( $\Delta\alpha$ ,  $\Delta\delta$ ) offsets are referred to the phase tracking center. The starred and filled squared markers show the positions of the dynamical center and the SNR41.95+57.5, respectively. The location of the radiocontinuum filament (RC) is highlighted by an arrow.

Fig. 2.— We compare the emission of SiO( $v=0, J=2-1$ ) (contour levels: -0.09, 0.09 to 0.35 Jy beam $^{-1}$  kms $^{-1}$  by steps of 0.025 Jy beam $^{-1}$  kms $^{-1}$ ) and H $^{13}$ CO $^+$  (gray scale: 0.09, 0.12 to 0.90 Jy beam $^{-1}$  kms $^{-1}$  by steps of 0.055 Jy beam $^{-1}$  kms $^{-1}$ ) integrated in three adjacent velocity intervals (shown in the top right corner), towards the center of M 82. The major axis and dynamical center are identified as done in Fig. 1.

